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(54) Method to tune the natural frequency of turbine blades by using the orientation of the secondary axes

(57) Tuning of turbine bucket torsional and stripe mode natural frequencies can be effected without altering any turbine bucket physical features, such as weight and/or shape, and without affecting flexure frequencies. The tuning of certain turbine bucket natural frequencies serves to avoid detrimental blade resonance, thus improving the reliability of a gas turbine. The method includes investment casting the turbine bucket with a single crystal alloy, and tuning the natural frequency of the turbine bucket without modifying physical features of the turbine bucket by placing a crystal seed along a desired direction according to a relative orientation of an engine axial direction.

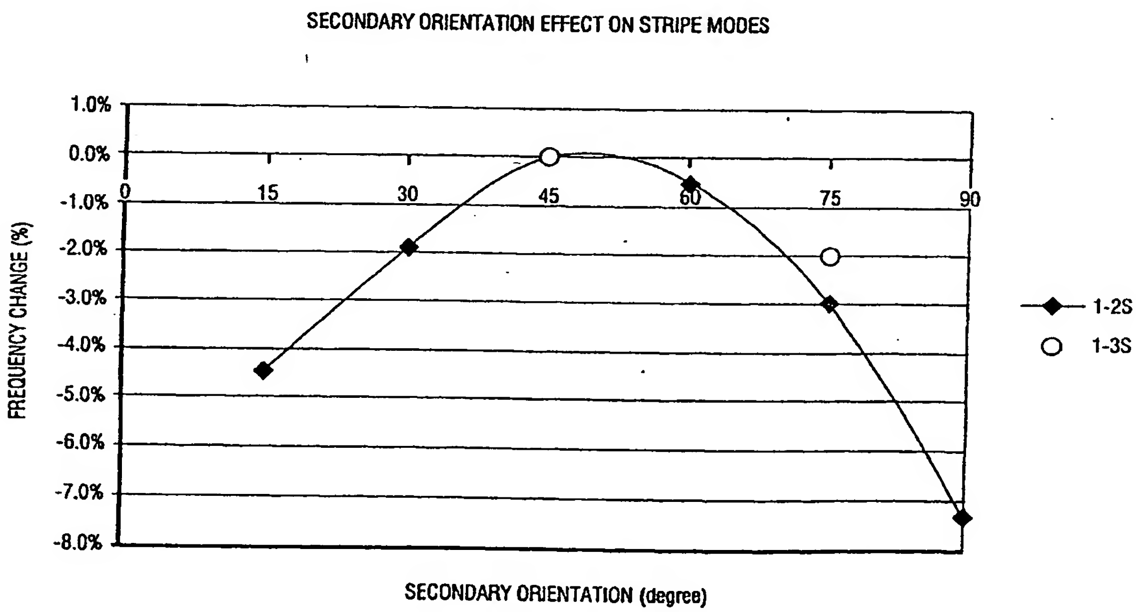

Fig. 3

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Description

[0001] This invention relates to gas turbine bucket construction and, more particularly, to using secondary orientation to tune turbine bucket natural frequencies.

[0002] As a rotational component in a gas turbine engine, the turbine blade or turbine bucket experiences different dynamic stimuli due to the aerodynamic disturbances from, for example, the up- and down-stream nozzles, the combustor cans, the tip shrouds, etc. When any of these stimulus frequencies is close enough to the natural frequency of the rotational turbine bucket, resonance may occur that will likely cause failures, usually catastrophic, to the bucket due to high cycle fatigue. Indeed, a large number of engine failures in the field can be traced back to the root cause of vibration related failures. Thus, it is important in bucket design to avoid resonance during operation by a sufficient margin.

[0003] Previously, tuning of bucket natural frequencies has been accomplished using airfoil thickness to chord ratio, trailing edge wedge angle, trailing edge mass, airfoil wall thickness, cooling cavity size and number, tip shroud or cap, and camber. These previous methods, however, typically require the alteration of some physical feature of the bucket such as bucket weight or shape and/or increased production costs or altering the flex modes when only torsional or stripe modes are needed to be tuned. It is thus desirable to effect tuning of bucket torsional and stripe mode natural frequencies without altering any bucket physical features, without increasing bucket manufacturing cost, and without affecting the turbine bucket flexure frequencies.

[0004] In an exemplary embodiment of the invention, a method of manufacturing a turbine bucket includes (a) investment casting the turbine bucket with a single crystal alloy, and (b) tuning a natural frequency of the turbine bucket without modifying physical features of the turbine bucket. Step (b) may be practiced by tuning the natural frequency of the turbine bucket without affecting turbine bucket weight or turbine bucket shape. Step (b) may also be practiced by tuning torsional and stripe mode frequencies without affecting flexure mode frequencies of the turbine bucket. In this context, step (b) is preferably practiced by, prior to step (a), placing the crystal seed along a desired direction according to an orientation relative to the engine axial direction.

[0005] In another exemplary embodiment of the invention, a method of tuning turbine bucket natural frequency includes (a) placing the crystal seed along a desired orientation relative to the engine axial direction, and (b) investment casting the turbine bucket with a single crystal alloy, wherein the desired orientation is selected to tune torsional frequencies without affecting flexure frequencies.

[0006] An embodiment of the invention will now be described, by way of example, with reference to the accompanying drawings, in which:

FIGURE 1 illustrates a crystal orientation relative to engine orientations;

FIGURE 2 is a graph showing the effect of secondary orientation on 1T and 2T frequencies; and

FIGURE 3 is a graph showing the effect of secondary orientation on 1-2S and 1-3S frequencies.

[0007] With reference to FIGURE 1, in a single crystal alloy, the material directions along the X' and Y' axes are termed secondary orientation, while that along the Z' direction is termed as the primary orientation. The secondary orientation is defined by the angle θ_s between the engine axial direction X and the material direction X, which is the same as the angle between the engine tangential direction Y and the material direction Y.

[0008] Operating frequencies of turbine buckets can be determined in the design phase using engineering models and the like as would be apparent to those of ordinary skill in the art. The data for FIGURES 2 and 3 is based on known Finite Element (FE) Analyses (known as ANSYS code) and is validated through engine tests. Similar engineering models by FE analyses can be used to determine bucket natural frequencies. As noted, it is important to avoid resonance by a sufficient margin to improve operating efficiency, and it thus may be necessary to "tune" the natural frequencies of a turbine bucket.

[0009] In a bucket of single crystal alloy, the shear modulus that determines the torsional frequencies is dependent on the secondary orientation θ_s. The tensile modulus along the radial direction that determines the flexure frequencies, on the other hand, is insensitive to the secondary orientation. Thus, with the method of the present invention, the secondary orientation can be used to tune the torsional frequencies without affecting the flexure frequencies. FIGURE 2 shows the change of 1T and 2T frequencies as a function of the secondary orientation. FIGURE 3 shows the change of 1-2S and 1-3S frequencies as a function of the secondary orientation. It is known that changes in the secondary orientation will not affect the flexure frequencies (such as 1 F, 2F, etc.). Moreover, the change in secondary orientation does not entail changes in turbine bucket weight and shape. To implement certain preferred secondary orientation in an investment casting process is a relatively easy operation, thus the impact is minimal on manufacturing cost.

[0010] As noted, the data for FIGURES 2 and 3 is derived from FE analyses. First analyses are conducted by incorporating the secondary orientation in the engineering model, then the results are correlated with the engine test results. Subsequently, the secondary orientation is varied, and the curves are completed.

[0011] Investment casting with a single crystal alloy is known, and the details of the casting process will not be described herein. A related investment 10 casting process is described in commonly-owned U.S. Patent No.

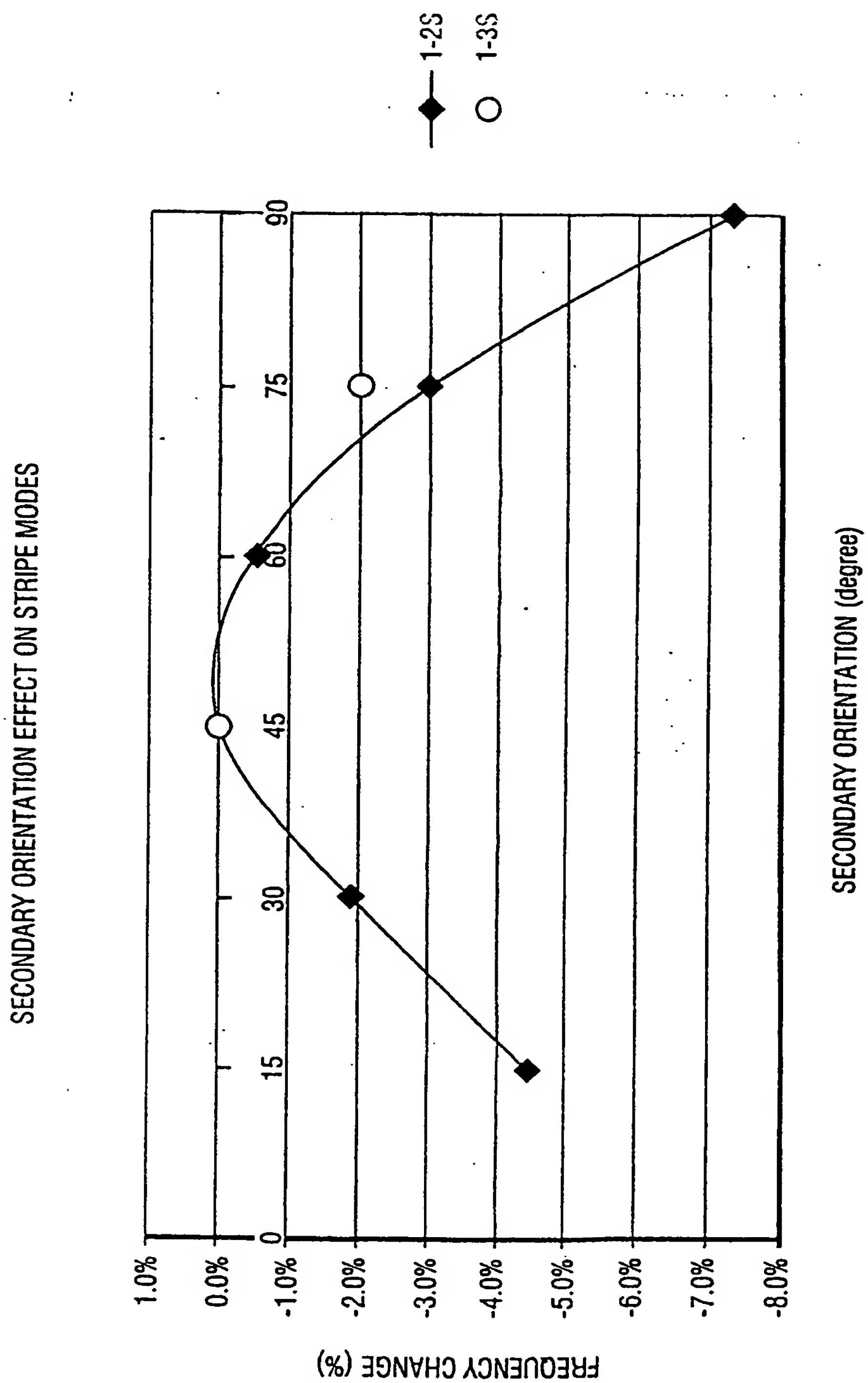
SECONDARY ORIENTATION EFFECT ON STRIPE MODES
1-2S
1-3S
FREQUENCY CHANGE (%)
1.0%
0.0%
-1.0%
-2.0%
-3.0%
-4.0%
-5.0%
-6.0%
-7.0%
-8.0%
0
15
30
45
60
75
90
SECONDARY ORIENTATION (degree)

Fig. 3

5,713,722.

[0012] In the investment casting process, the secondary orientation is controlled by placing the crystal seed along a desired direction. Placing of the crystal seed in the investment casting process does not affect the physical features of the turbine bucket, such as the bucket weight or shape, and does not entail any additional manufacturing operation or cost. As shown in FIGURES 2 and 3, the desired direction of the crystal seed or secondary orientation is selected to effect a desired percentage change in turbine bucket natural frequencies.

Claims

1. A method of manufacturing a turbine bucket comprising:

    (a) investment casting the turbine bucket with a single crystal alloy; and
    (b) tuning a natural frequency of the turbine bucket without modifying physical features of the turbine bucket.

2. A method according to claim 1, wherein step (b) is practiced by tuning the natural frequency of the turbine bucket without affecting turbine bucket weight.

3. A method according to claim 1, wherein step (b) is practiced by tuning the natural frequency of the turbine bucket without affecting turbine bucket shape.

4. A method according to claim 1, wherein step (b) is practiced by tuning torsional and stripe mode frequencies without affecting flexure mode frequencies of the turbine bucket.

5. A method according to claim 1, wherein step (b) is practiced by, prior to step (a), placing a crystal seed along a desired direction according to an orientation relative to an engine axial direction.

6. A method of tuning turbine bucket natural frequency comprising:

    (a) placing a crystal seed along a desired orientation relative to an engine axial direction; and
    (b) investment casting the turbine bucket with a single crystal alloy, wherein the desired orientation is selected to tune torsional frequencies without affecting flexure frequencies.

7. A method according to claim 6, comprising tuning the natural frequency of the turbine bucket without affecting turbine bucket weight. 51 DV-6081

8. A method according to claim 6, comprising tuning the natural frequency of the turbine bucket without affecting turbine bucket shape.

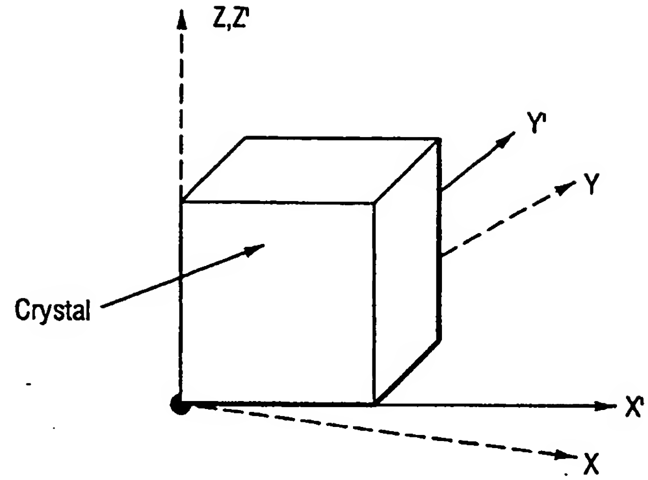
Z,Z'
Y'
Y
Crystal
X'
X

Fig. 1

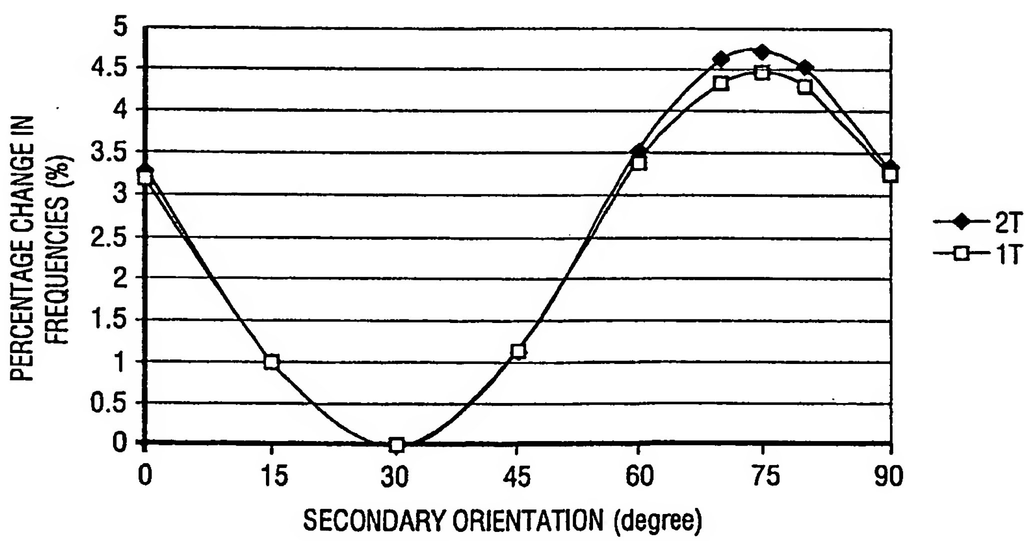
PERCENTAGE CHANGE IN FREQUENCIES (%)
5
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
0
15
30
45
60
75
90
SECONDARY ORIENTATION (degree)
2T
1T

Fig. 2